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ENERGY EFFICIENCY ECONOMICS OF CONVERSION OF BIOGAS FROM THE FERMENTATION OF SEWAGE SLUDGE TO BIOMETHANE AS A FUEL FOR AUTOMOTIVE VEHICLES

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Abstract

The paper presents the analysis of efficiency and energy economics potential applicability of biomethane as an alternative fuel for powering company owned motor vehicles and public transport vehicles produced by the conversion of surplus biogas generated in municipal sewage treatment plants. Biogas produced at municipal wastewater treatment plants in the process of anaerobic fermentation of sewage sludge is a source of renewable energy used for energy generation. Currently in Poland, the most commonly applied management method of biogas produced from sewage sludge involves the production of energy in a cogeneration system. Having in mind the condition of the natural environment, the search for alternative fuels for motor vehicles is underway. One of the types that can be used is biomethane, produced by the conversion of biogas produced in the fermentation process of organic wastes contained in sewage sludge. The biogas purified to contain about 95% of methane can be used in vehicles designed to burn gaseous fuel. In order to implement the conversion process of biogas to biomethane, it is necessary to work out a balance sheet of biogas produced at the sewage treatment plant, to study its chemical composition and to select the optimal technology to obtain high-energy gas fuel that meets required standards. In the course of the biogas conversion process, carbon dioxide is removed, which is regarded here as the so-called energy ballast. The technology used for powering motor vehicles by means of biomethane has been successfully implemented in many countries of the European Union. In view of environmental considerations, the proposed solution is generally supported because biomethane-powered engines have lower levels of emissions harmful to people and the environment.

Keywords: **Biogas; Biomethane; Biofuel; Emission to the air; Energy Efficiency Economics; Sewage treatment plant; Water scrubber, Biogas treatment.**

1. INTRODUCTION

Basing on the data provided by the Central Statistical Office, in 2016 the length of the sewerage network in Poland exceeded 154 thousand kilometers, with the number of connections to buildings being approx. 3.2 million. The volume of sewage discharged from households in 2016 amounted to 938.1 hm3. The generated municipal sewage is subjected to treatment processes in over three thousand treatment plants, of which 106 produce biogas from the fermentation of sewage sludge [1].

Presently, sewage networks have extensive infrastructure that requires the use of control systems, e.g. an intelligent multithreaded system, hierarchical prediction control with the use of parallel computational architecture. Such solutions are implemented mainly in high inertia networks, including very large ones, in order to ensure continuous and laminar supplies of municipal sewage. Such asituation ensures the stability of the wastewater treatment process and consequently the optimal quality of sewage sludge as an energy raw material for further biogas production processes. The biogas generated at the municipal wastewater treatment plant in the process of anaerobic fermentation of sewage sludge is a source of renewable energy. The use of biogas for energy purposes at sewage plants necessitates the adoption of appropriate conditioning procedures to remove contaminants such as sulfur compounds, siloxanes, nitrogen, ammonia, water. Presently, the most commonly used management method of biogas produced in Polish municipal wastewater treatment plants involves its application for technological purposes as energy source and in combined systems (cogeneration) aimed to generate electricity and heat. In the view of new technologies being development for biogas energy generation purposes as well as current changes in the promotion of energy produced from renewable sources, alternative prospects encouraging its application are arising. In the near future, the cogeneration (CHP – Combined Heat and Power) can be supplemented by such developments as biogas conversion to biomethane and its application, e.g. as fuel for vehicle propulsion. Wastewater treatment plants that have surplus biogas in terms of the existing capacities of cogeneration units, can build biogas treatment installations for biomethane to supply their own vehicles or sell it as compressed biomethane (CBG – Compressed Biomethane Gas). The biogas which is to be used to supply car engines must be subjected to treatment processes in order to increase its energy value. The objective underlying the selection of an appropriate treatment technology is to increase the content of methane and to eliminate substances harmful to engines such as carbon dioxide, hydrogensulphide, siloxanes or water vapor. The main advantage of using biomethane lies in its ecological value as a fuel viewed as a source of renewable energy [2, 3, 4].

The application of biomethane as engine fuel, apart from the impact of the commercial aspect following the use of biomethane-based fuel, has significant benefits for the natural environment. Internal combustion engines powered with biomethane, as compared for example to engines powered with diesel, are characterized by lower levels of emissions of such pollutants as solid particles and polycyclic aromatic hydrocarbons, as well as by lower noise levels. This is particularly important when vehicles powered with biomethane run through precious areas of natural beauty or through city areas, including historic building developments [5].

2. CURRENT STATUS AND ECONOMIC ASPECTS OF BIOGAS PRODUCTION IN POLAND

The Act on renewable energy sources defines biogas as the gas obtained from biomass, in particular from the installations for the processing of animal wastes or vegetable wastes, from sewage treatment plants and landfills [6]. Depending on the source, its chemical composition may vary considerably. The basic combustible component of biogas is methane, which in 90% is generated in the decomposition process of cellulosic wastes. The optimal parameters of biogas used for energy production purposes should be contained in the following ranges: methane 35÷70%, carbon dioxide 20÷50%, nitrogen 0÷5%, hydrogen 1÷2%, oxygen 2% and trace amounts of other compounds such as hydrogen chloride, alkaline compounds, hydrogen sulphide, siloxanes or ammonia [7, 8].

Balance sheet data on biogas with the specification of its origin: from landfills, sewage treatment plants and others are presented in Fig. 1. In the years 2012–2016, the volume of produced biogas was systematically rising. The largest increase in biogas production was reported in the group of "other biogas",which was almost 2.4 times higher compared to the year 2012. The acquisition of biogas from sewage treatment plants increased in 2016 1.5 times compared to 2012, while the acquisition of biogas from landfills was maintained at a similar level in the discussed period. Biogas is mainly used as the input in energy transformation processes (generation of electric power and heat) [9].

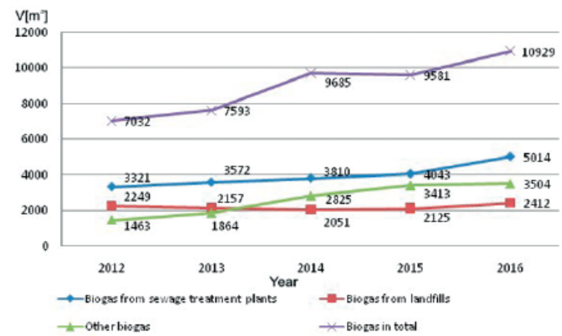

Figure 1.
Acquisition of biogas in the years 2011–2016 [9]

The production of biogas as a renewable energy source is a process having high energy potential and large applicability perspectives involving its management. The profitability of biogas production is depended on such factors as rising energy prices, installation costs, specific performance, etc., and can range from 30 to 50%. The biodegradable raw materials used in the process of anaerobic fermentation, especially those classified as wastes (sewage sludge), contribute to the reduction of their volume and to the implementation of waste-free economy in real conditions. With each passing year, the volume of biogas produced at municipal wastewater treatment plants is increasing. Currently in Poland, the biogas produced at municipal wastewater treatment plants is most frequently used for heat production for technological purposes and in cogeneration systems for the generation of electricity and heat, used mainly for the needs of the plant's own objects. The main objectives for the incoming years in this area will involve further optimization of its production and the diversification of application opportunities [10].

3. CONVERSION TECHNOLOGIES OF BIOMETHANE TO BIOGAS

By using appropriate technologies for the treatment and purification of biogas, mainly by removing carbon dioxide, we can obtain gas with the methane content of over 95%. Biogas treatment technologies are being constantly developed. The review of technologies presented, among others, by Johansson N. and the research studies described by Cebula J. and Persson N. et al., demonstrates that there are technical potentials that can contribute to a more efficient and cheaper production of biomethane, and thus to further rise in its application as an alternative fuel to fossil raw materials. Most biogas treatment technologies have been adapted from the well-known technologies used for refining natural gas. However, the specificity of biogas, which involves a diverse chemical composition of its parameters, conditions of the fermentation process and the size of installation, call for the development of new or modified treatment technologies, used solely for efficient biogas treatment. Table 1 presents the chemical composition of biogas produced from sewage sludge at selected treatment plants in Poland for similar outputs of a given treatment plant [7, 8, 11, 12, 13, 14].

Table 1.
Chemical composition of biogas at selected treatment plants in Poland [7, 8, 12, 15]

Treatment plant	CH_4 [%]	CO_2 [%]	O_2 [%]	N_2 [%]	H_2S [ppm]
Object 1	62.3	36.4	0.4	0.6	384
Object 2	63.6	35.2	0.1	0.8	25.3
Object 3	62.6	35.4	0.3	0.4	15.1
Object 4	59.8	36.9	0.1	2.1	62.1
Object 5	61.5	38.2	0.02	0.15	19.4
Object 6	64.4	34.3	0.2	0.5	147

The research conducted on the basic parameters of biogas produced in the process of anaerobic fermentation of sewage sludge from the 6 selected treatment plants in Poland demonstrates that there are differences in its individual parameters. This is primarily due to the parameters of raw sewage supplied to the treatment plant, the kind of technology used to prepare the sludge for fermentation and the parameters applied to conduct the fermentation process. The smallest deviations are recorded for the content of methane in biogas, which bespeaks of process stabilization and high calorific value. Currently, when we consider conversion technologies of biogas to biomonide available on the market, we can distinguish six basic technologies for biogas purification and treatment, which are presented in Table 2. Depending on the used method, the efficiency of the process will vary, while biomethane as the final product will have the content of methane in the range of 95÷99%. The losses, depending on the used technology in the entire processing procedure, can account for up to 10% of the methane input volume [6, 14, 16].

Table 2.
Technologies of biogas treatment and purification [6]

Technology	Conditions of the process	Content of methane after the process %	Methane loss %
Water scrubber (physical absorption)	Pressure absorption of CO_2 In water	98	1÷2
Organic scrubber (physical absorption)	Pressure absorption of CO_2 in the organic solvent	>96	2÷4
Pressure adsorption (PSA)	Absorption of CO_2 under pressure on activated carbon	>96	3÷10
Chemical absorption	Chemical reaction of CO_2 with the solution of amines : non-pressure process, high temperature	99÷99.4	< 0.1
Cryogenic separation	Compression and cooling in several stages: CO_2 separated in liquid form	95÷98	0.5
Membrane separation	Permeation of gas molecules under pressure	>95	2

The technologies presented above vary in the amount of operating costs, maintenance, consumption of materials or chemicals and environmental impact. But their main objective is to improve the quality of biogas and its energy parameters in the purification and treatment processes of biogas in order to achieve parameters similar to those of natural gas. In Europe, the most commonly used technologies are adsorption (PSA) and water scrubbers. Both technologies have been used in over 60 installations, most of which are located in Germany and Sweden. Other technologies have been implemented in individual facilities inEurope. The currently operating water scrubbers in Europe produce biomethane with the content of methane being approximately 97% by volume. One of the largest installations of this type in Europe is currently in operation in Madrid, where approximately 4,000 m^3/h of raw biogas is subjected to conversion. The biomethane produced in Europe and worldwide is mainly used as fuel for the propulsion of motor vehicles and pumped into the network of natural gas. Currently, the only installation for the conversion of landfill biogas to biomethane is operating in Poland. It was launched in 2015 as part of the More Baltic Biogas Bus international project. The installation is based on the water scrubber technology. The biogas purified in this technology is referred to as biomethane. It is used for the propulsion of buses, and it is principally a research installation. Currently in Poland there are no conversion installations of biogas to biomethane which apply biogas from the fermentation of sewage sludge at sewage treatment plant [12, 13, 17].

4. DESCRIPTION OF THE FACILITY FOR BIOGAS GENERATION

The analysis involves potential prospects of using biogas conversion to biomethane at the municipal wastewater treatment plant as a way to utilize the surplus of the produced biogas which is currently burned in a gas flare. The biomethane produced in this way will be applied as fuel for powering a fraction of motor vehicles owned by the plant, and as renewable fuel for powering city buses. The facility used for the production of biogas is located at a municipal wastewater treatment plant of a design capacity of PE of 180,000 and real-time average flow of 23 327 m^3/day in 2017. Wastewater quality tests carried out in an accredited laboratory by the operator of the installation are presented in Table 3.

Table 3.
Average concentrations of pollutants in the sewage inflowing and treated at the sewage treatment plant in 2017 [10]

Parameter	Raw sewage	Required values	Treated sewage [mg/l]
BZT_5	414	15	4.23
ChZT	1042	125	43.1
POG	7.32	1	0.32
$N_{Cał}$	63.8	10	8.41
Total suspension	448	35	13
Ether extract	170	50	14.8
Petroleum substances	1.2	15	0.067

Table 4.
Selected biogas parameters after the purification process [10]

No	Parameter	Unit	Result
1.	Methane (CH_4)	%	66.42
2.	Carbon dioxide (CO_2)	%	33.0
3.	Hydrogen (H_2)	%	0.01
4.	Hydrogen sulfide (H_2S)	ppm	15
5.	Oxide (O_2)	%	not found
6.	Heat of combustion	MJ/m^3	26.45
7.	Calorific value	MJ/m^3	23.78
8.	Wobbe number	MJ/m^3	28.27

At present, in the premises of the sewage treatment plant, a sewage sludge installation producing biogas is operating. The biogas is used to generate electricity and heat in a biogas cogeneration unit of the electrical power of 372 kW and heat power of 541 kW, or it is burned in gas boilers. In 2017, the sewage treatment plant was supplied with over 8.5 million m^3 of sewage. The mixed sludges – primary and surplus ones, are transferred to two separated, closed fermentation chambers of the total capacity of 4500 m^3, where they are stabilized in anaerobic methane fermentation carried out at 37-40°C. The sludge retention time in the chambers is from 18 to 25 days. The biogas accumulated in the upper part of the fermentation chambers is collected and transported by pipelines to a biogas tank of the volume of approx. 1040 m^3, in front of which biogas coolers along with a steam trap are mounted to get rid of excess moisture in the biogas. In the next stage of biogas conditioning, it is purified from sulfur compounds following the contact with the aqueous solution of the catalyst. The biogas so purified is passed to a cogeneration unit or boilers. Table 4 below presents the chemical composition of the purified biogas based on the biogas tests conducted by the operator of the biogas generation installation.

The biogas produced at sewage treatment plants has very good energy parameters, and therefore, it is used to produce electric power and heat in the cogeneration system, or to generate heat in the combustion process in gas furnaces. Electricity is entirely intended to supply the machinery and equipment in the premises of the plant, and the surplus is transferred to the external power grid. The heat produced in cogeneration units, or separately in gas boilers (only during breaks in the operation of the cogeneration unit) is used for technological and social purposes. Table 5 presents the volume of biogas produced in the sewage treatment plant in 2017, including the volume used for energy in the cogeneration unit and the surplus that remained to be managed [10].

The balance sheet of the production and use of biogas derived from the fermentation of sewage sludge at the sewage treatment plant indicates the surplus of the volume of produced biogas as compared to its

Table 5.
Balance sheet of the produced biogas and the method of its use. Own study based on [10]

Year 2017	The volume of produced biogas [m^3]	The volume of biogas used to generate electricity [m^3]	The amount of produced electricity [kWh]	Surplus of biogas [m^3]
January	149360.0	112750.2	243117.6	36609.8
February	149422.0	100493.0	216688.0	48929.0
March	159233.0	105714.6	227947.0	53518.4
April	156868.0	111400.8	240208.0	45467.2
May	150001.0	113688.1	245140.0	36312.9
June	138283.0	107784.3	232410.0	30498.7
July	137858.0	80782.5	174187.2	57075.5
August	129037.0	102972.3	222034.0	26064.7
September	122893.0	94832.2	204482.0	28060.8
October	134820.0	107126.7	230992.0	27693.3
November	146462.0	107869.5	232593.6	38592.5
December	161615.0	115133.2	248256.0	46481.8
Total	**1735852.0**	**1260547.4**	**2718055.4**	**475304.6**

potential in terms of energy-production application in the cogeneration unit. The surplus in question is systematically burned in a gas flare. Considering the above, a suggestion was put forward to consider the possibility of implementing a conversion installation of biogas to biomethane in order to produce fuel and supply it primarily to vehicles operating at the sewage treatment plant, but also to other vehicles owned by the Company, moving mainly around the city, as well as to public transport vehicles. The objective of the analysis carried out by the authors was to replace the conventional fuel with renewable fuel produced from biogas in the context of environmental protection by reducing exhaust emissions resulting from the combustion of fossil fuels (ethyl gasoline, diesel) in the internal combustion engines of these vehicles. Pollutants emitted into the air by exhaust gases from motor vehicles and vapors of such fuels such as gasoline or diesel have a negative impact on air quality, the environment and human health. It is estimated that current fuel consumption in road transport can be the source of over 20% of global carbon dioxide emissions [20].

5. BIOMETHANE AS A FUEL FOR POWERING VEHICLES

A good example of the adoption of biomethane (CBG – Compressed Biomethane Gas) as a transport fuel are such European countries such as Germany, Austria or Sweden. In Sweden, biomethane is successfully used in public transport as a fuel, e.g. for powering the engines of public transport buses. The target objective for the capital of Sweden – Stockholm in terms of the application of renewable energy sources (RES) in 2010 was to convert 40% of the bus fleet and adapt them to use fuel from renewable energy sources, and in 2011 the objective was raised to 50%. According to forecasts, in 2025, the entire fleet of city buses in Stockholm will be powered exclusively by the so-called "renewable fuels" (biomethane, biodiesel, bioethanol) [5]. Following the analysis of available conversion technologies of biogas into biomethane at the sewage treatment plant, we proposed to apply a system of physical absorption based on water scrubber (pressure absorption of CO_2 in water), which is presented in Figure 2. It is one of the most popular biogas treatment techniques due to simple structure of installation components, uncomplicated operation and maintenance, relatively low investment costs and low process losses. The said method consists in dissolving carbon dioxide in water, which is released in the desorption column and, together with the air injected into the column, is removed from the column after the separation from the water. The diagram of the installation is presented in Figure 2. The separation of methane from carbon dioxide is caused by the difference in the solubility of carbon dioxide and methane (the solubility of CO_2 at 25°C is about 26 times higher than that of CH_4 [6, 12, 14].

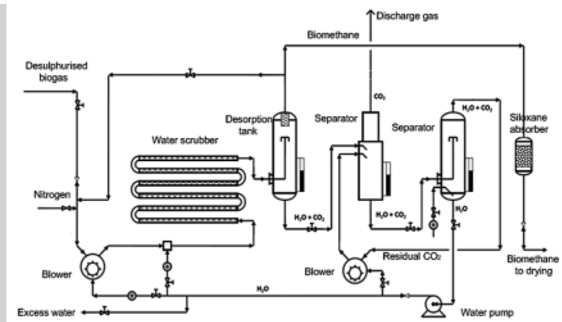

Figure 2.
Installation for the conversion of biogas to biomethane

The total surplus of produced biogas at municipal sewage treatment plant in 2017 amounted to the volume of 475,305 m^3, whereof 102 580 m^3 was burned in gas boilers as a fuel to generate heat for technological purposes, while the remaining volume, i.e. 372,725 m^3 of biogas, was burnt in 2017 in a gas flare without energy recovery. And it is the latter volume of biogas that is planned to be used in the biogas conversion installation of the treatment plant. The surplus of biogas not used in the cogeneration system and not burnt in the gas boilers will be stored in the biogas tank and systematically transferred to the biomethane conversion installation. In order to calculate the capacity of the installation at the input of biogas and the volume of biomethane production in the installation per year, we assumed an average annual methane content in biogas at 60%, operation time of the installation up to 12 hours a day and methane content in biomethane at 97%. Taking into consideration the potential volume of biogas intended for management, we assumed the installation's efficiency at the input of biogas at the level of 100 m^3 of biogas per hour. The installation ensures drying of biogas, the removal of carbon dioxide excess, sulfur compounds and other undesirable contaminants, and then the biomethane is compressed and stored under the pressure of 250 bar in containers adapted for this purpose. The installation should be built on the basis of two containers. One container should comprise the equipment for biogas treatment to adopt it to engine fuel parameters, while the other one should contain a compressor, anabsorber soaking up residual biomethane water and biomethane storage tanks. On the outer wall of the second container, a distributor should be installed for filling up car tanks with biomethane (CBG). The average hourly yield of biomethane recovery from the installation is limited by the compressor's efficiency for the produced biomethane and it should amount to 60 Nm^3/h. Based on the operating data of the system of biogas conversion to biomethane which are currently adopting the technologies based on physical absorption with the use of water scrubber, the parameters of the obtained fuel (biomethane) should be reflecting the values listed in Table 4. The volume of biogas in the amount of 372,725 m^3 making up the input stream into the installation will allow the production of approximately 223,635 m^3 of biomethane per year with the methane content of approximately 97%. Taking into account the parameters of the produced biomethane, which are comparable to natural gas parameters, the produced gas fuel can be used similarly to CNG gas fuel for powering automotive vehicles. The carried out research studies on the parameters of biogas in the conversion process to biomethane described e.g. by Reith J.H. et al., confirm process stability and the repeatability of physicochemical parameters of biomethane [5, 10, 17].

The produced gas fuel in the form of biomethane will be intended to supply 8 own have goods vehicles, including specialist vehicles serving the needs of the Sewage Treatment Plant, Water Intake Plant and Piping Network Plant, which are facilities belonging to the municipal company. Additionally, biomethane will be supplied to 4 public transport buses running in the city area, which also belong to the municipal company. In effect of the application of biomethane to power motor vehicles, about 228,555 dm^3/year of diesel fuel will be eliminated from use, which will be replaced by biomethane (CBG) in the amount of 223 635 m^3/year.

6. ENVIRONMENTAL ASPECTS INVOLVING THE USE OF BIOMETHANE IN TRANSPORTATION

Trucks and public transport are an example of segments of the automotive industry which have a very large negative impact on the natural environment due to large amounts of consumed fuel. This is due to specific conditions, especially in the case of public transport in heavily populated and built-up agglomerations, where the vehicles frequently stop at bus stops, they have higher fuel consumption and generate noise pollution. With this in mind, bus manufacturers have introduced vehicles powered by alternative fuels, including compressed natural gas (CNG). The biogas produced at a sewage treatment plant after its processing can be directly used as a CBG vehicle fuel. It is interesting to note that the existing infrastructure of CNG refueling stations could be used for the distribution of biomethane and the use of biomethane in vehicles already powered by compressed natural gas, which could contribute to its popularization [22].

For the purpose of full environmental assessment, including pollutant emissions and comparative analysis involving the combustion of various fuels, a fuel lifecycle analysis is performed. For fossil fuels, the analysis is referred to as “Well-To-Wheel” (WTW), and covers all processes related to the acquisition of fuel, production, transport, storage, emissions related to the use of fuel in the vehicle such as its refueling and combustion in the engine. For the biomethane

Table 6.
Comparison of the composition of individual types of gases. Own study based on [21]

Parameter	Biogas from treatment plant	Biomethane	Natural gas
Methane	66.42%	97%	93 – 98%
Carbon dioxide	33.0%	2.3%	3%
Nitrogen	<3%	<2%	<1%
Oxygen	<1%	<1%	≤0.2%
Hydrogen sulphide	1.59 mg/m^3	<1 mg/m^3	7.0 mg/m^3
Siloxanes	5.9 mg/m^3	-	-
Heat of combustion	26.45 MJ/m^3	31 MJ/m^3	30–34 MJ/m^3
Wobbe number	28.27 MJ/m^3	39 MJ/m^3	37.5–45 MJ/m^3

Table 7.
Annual volume of carbon dioxide emissions for selected types of motor vehicles [23]

Type of vehicle	Annual emission of CO_2 [Mg/year]			Percentage change in emission [%]	
	petrol/diesel	Natural gas	Biomethane	Natural gas vs. petrol / diesel	Biomethane vs.petrol / diesel
Truck up to 3.5 t (petrol)	1.70	1.39	0.20	-18	-88
Truck up to 3.5 t (diesel)	1.31	1.39	0.20	+6	-85
Truck 3.5 to 12 tons (diesel)	18.7	20.43	4.91	+13	-73
Truck 12 to 26 tons (diesel)	48.21	55.94	10.61	+16	-78
Bus (diesel)	57.53	60.96	10.10	+15	-82

produced from biodegradable waste, the environmental assessment based on lifecycle analysis is called "Waste-To-Wheel", and includes the emissions of pollutants into the air generated in the course of all operations and processes covering waste collection, transport, storage, biogas production, treatment, processing to biomethane, distribution, storage, filling upthe vehicle and the process of its combustion in the engine. The results of the carried out tests and analyses concerning the emissions from various types of fuels are presented in Table 7, allowing for the selected types of motor vehicles [23, 20].

The replacement of diesel with biomethane in internal combustion engines of the vehicles used at the water supply company and at the public transport company will bring about a real reduction of the emission of harmful substances into the environment, whereof selected types are presented in Table 8.

Table 8.
Emissions of selected engine fuel pollutants [24]

Lp.	Fuel type	CO [g/km]	HF [g/km]	NO_x [g/km]	CO_2 [g/km]
1	Diesel	0.20	0.40	9.73	0.100
2	Naturalgas	0.40	0.60	1.10	0.022
3	Biomethane	0.08	0.35	5.40	0.015

The replacement of diesel with biomethane in heavy-duty vehicles of the water supply company and public transport company, when covering the distance of 491,200 km per year, will result in the reduction of emissions to the environment: CO_2 by 85%, Co by 66.67%, NO_x by 44.5% and HF by 12.5%. The most practical way to apply biomethane for transport purposes would be the construction of the installation located in the vicinity the sewage treatment plant. The installation of biogas treatment adopting it to engine fuel parameters should be also complemented with a compressor, an absorber taking in residual biomethane water as well as biomethane storage tanks. In further perspective, it is also recommended to install a refueling station for vehicles with at least one fuel pump [24].

At present in Poland there are no economic operators who are commercially using biogas collected from sewage treatment plants for its conversion to biomethane, or who have their own refueling station, use biomethane for their own transport purposes, sell outside, or supply it to CNG filling stations. The use of biomethane as an engine fuel, apart from the direct commercial benefits involving the application of biomethane as a fuel, has also significant environmental advantages. Combustion engines powered by biomethane are characterized by lower levels of pollutants harmful to human health, such as solid particles and polycyclic aromatic hydrocarbons, in contrast to diesel engines. It is estimated that the use of biomethane instead of traditional fuels derived from fossil raw materials should contribute to the reduction of CO_2 emissions by 75 to 100% [17, 22, 23–27].

7. CONCLUSION

The conversion of landfill biogas to biomethane is one of possible alternatives to biogas combustion aimed to generate electricity and heat. Available biogas purification and treatment technologies enable the acquisition of the parameters landfill biogas in the form of biomethane corresponding to the parameters of natural gas. The technology adopted for powering engine vehicles with biomethane, principally municipal vehicles or public transport buses, is a technology of the future that has been successfully implemented in many countries of the European Union. Such a solution is beneficial in terms of environmental issues because biomethane powered engines have lower levels of emissions hazardous to people and to the environment. The application of sewage sludge for the production of biogas, purified to the quality of natural gas (CBG biomethane), should be the optimal solution which can yield a very useful and ecological fuel produced in the fermentation process of sewage sludge (waste).

Biomethane is a prospective gas biofuel applicable in internal combustion engines of trucks and public transport buses. High production potential of biogas and its good physical properties such as fuel as well as positive environmental aspects, should provide good grounds to carry out further research studies and consequently to spark commercial initiatives involving the conversion of biogas to biomethane in view of its common applications. The solutions applied on the European market, especially in Germany and Sweden, should serve as an example for other European countries, including Poland in terms of biogas (biomethane) applications as a transport fuel.

The value of CO_2 emission in the case of biomass-derived fuels is zero, because the carbon dioxide emitted in effect of the combustion of biomethane in the engine is a decomposition product of organic matter and is subjected to the sequestration of carbon from the atmosphere, as a result of which it is generated again. The sequestration and following it CO emission create a sustainable cycle of production and use of biomethane, as opposed to fossil fuels where the amount of CO in the atmosphere increases. Biogas production is also of economic, social and economic importance. It is a kind of complement to the ecological lifecycle of waste, which combines waste management with the production of clean energy in the form of biofuel for powering motor vehicles.

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